

**A PROGRAM TO DETECT AND CHARACTERIZE
EXTRA-SOLAR GIANT PLANETS**

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**Progress Report for NASA Grant NAG5-10854,
“A Program to Detect and Characterize Extra-Solar Giant Planets”
Robert W. Noyes
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This is a progress report for the second year (from 5/1/2002 to 4/30/2003) of the three-year Grant NAG5-10854.

Summary of Work

1. AFOE Upgrade

We initiated a significant hardware upgrade to the AFOE, to increase its efficiency for precise radial velocity studies to the level where we can continue to contribute usefully to extrasolar planet research on relatively bright stars. The AFOE, at a 1.5-m telescope, will of course not have the sensitivity of radial velocity instruments at larger telescopes, such as the HIRES on Keck or the Hectochelle on the MMT telescope (about to come on line). However, it has been possible to increase its efficiency for precise radial velocity studies by a factor of 4 to 5, which—combined with the large amount of telescope time available at the 1.5-m telescope—will permit us to do intensive follow-up observations of stars brighter than about 8 magnitude. The AFOE was originally designed primarily for asteroseismology using a ThAr reference. This provided useful wavelength stability over tens of minutes as required for asteroseismology, but we were unable to get a long-term (month-to-month) velocity precision better than about 15 m/s with that setup. Hence, we implemented an iodine cell as a wavelength reference for extrasolar planet studies. However, the optical design of the original AFOE did not completely span the wavelength range covered by the iodine absorption spectrum, and furthermore the optics suffered significant light loss through optical obscuration in the camera secondary. To remedy this, we replaced the AFOE grating with a new one that covered the entire iodine spectral range at somewhat lower spectral resolution, and replaced the camera with a transmitting lens. (The use of a lens was made possible by restricting the spectral range covered by the upgraded AFOE to only the iodine region.)

These upgrades were successfully completed, and the instrument was tested for three nights in fall of 2002. The expected improvement in sensitivity by a factor of 4 to 5 was observed: that is, the same velocity precision as previously attained (of order 5 to 7 m/s) was now obtained on stars that are about 4 to 5 times fainter.

Unfortunately, just after installing the new AFOE optics, there was a catastrophic failure of the old Tektronix CCD. A careful investigation was made, and it was determined that the failure was probably due to too many thermal cyclings over the previous 8 years. The only solution was to purchase a new CCD. Internal funds of \$16,000 were found for this purpose, and the new CCD (a thinned, back-illuminated Marconi 2K x 2K device with 13.5 micron pixels, and employing dual readout channels to keep the readout time as short as 20 seconds) was ordered, has now arrived, and is currently under test before

being installed in the AFOE liquid nitrogen dewar. At the same time, we expect to implement new CCD control electronics. This system should be better in many ways than the previous detector (including eliminating the need for UV flashing to maximize the quantum efficiency). We plan to install the detector on the telescope and begin operations again in April of this year.

2. Precise radial velocity observations with the MMT Hectochelle

The MMT Hectochelle is a multi-object echelle spectrograph, which can record the spectra of up to 300 stars within the 1 degree field of the MMT's f/5 secondary. This instrument will finally come on line by fall of 2003, in time for its use for radial velocity studies during the third year of this grant. In preparation for this, we have been developing iodine cells as a precise wavelength reference. These cells are very non-standard, because of the special geometry of the multi-fiber feet of the Hectochelle. The iodine cells have now been built, and their spectrum scanned at the McMath Fourier Transform Spectrometer at Kitt Peak. They are now being integrated into the Hectochelle.

For our radial velocity work with the Hectochelle will use only a single echelle order since we do not yet have a cross-disperser that would allow us to use the full I2 spectral range. This means a several-fold loss of efficiency over what will be possible if the Hectochelle is later equipped with a cross-dispersing prism; however, the ability to obtain simultaneous data on hundreds of stars in a field will more than make up for that loss for observations in rich fields. In such cases the 6.5-m aperture of the MMT will make the Hectochelle an extremely efficient instrument for extra-solar planet research. One important application we are planning to pursue is to image a large number of stars within 1-degree subfields of the *Kepler* mission field. For stars brighter than about 12 magnitude, we should be able to get sufficient precision in a few hours observation to detect "hot Jupiters", i.e. close-in giant planets with semi-major axes of order .05 AU, similar to 51 Peg b and a number of other hot Jupiters orbiting nearby stars. By identifying a number of hot Jupiters within the *Kepler* field before that mission flies, we will help enable the *Kepler* team to focus on those particular stars for photometric data retrieval; these planets should have enough reflected light intensity ratio (a few times 10^{-5}), so as to be detectable with the expected photometric precision of *Kepler*. Thus, armed not only with the knowledge of which stars have hot Jupiters, but also what the period and phasing of their orbits is), it should be possible to readily detect the photometric variations of these planets and actually measure the phase curves of their reflected light variations. This will tell us a great deal about not only their albedo but other properties of their atmospheres such as composition and particle size of clouds. Such results would amount to very important early science return from the mission—long before terrestrial planets are detected later in the mission. As the time for scientific operations with the Hectochelle approaches, we are making plans for an observational program to pursue this idea (among other uses of the Hectochelle for radial velocity work in clusters, as originally proposed for this grant).

3. The Transiting Planet HD 209458b

During the second year of the program we continued our work on the transiting planet HD 209458 b, using observations with the Space Telescope Imaging Spectrometer on STIS.

We were able to detect the presence of sodium vapor in the planet's atmosphere, due to significantly increased absorption in the sodium D lines during the time of transit. This is the first detection and measurement of the properties of a planet atmosphere outside our solar system. A paper detailing these results was published: Charbonneau, Brown, Noyes, Gilliland, "Detection of an Extrasolar Planet Atmosphere", 2002, ApJ 568, 377. The results reported in this paper were sufficiently important to merit a NASA Space Science Update, and were also singled in the NASA Office of Space Science GPRA report on progress on its Enterprise Science Objectives as follows: "Astronomers using NASA's Hubble Space Telescope have made the first direct detection of the atmosphere of a planet orbiting a star outside our solar system and have obtained the first information about its chemical composition. Their unique observations demonstrate that it is possible with Hubble and other telescopes to measure the chemical makeup of extrasolar planet atmospheres and to potentially search for chemical markers of life beyond Earth."

We also are collaborating with David Charbonneau (PI) on a follow-on HST STIS observation of HD 209458. Data were obtained during the time of eclipse of the planet by the star, in search of the decrease of intensity as the reflected light from the planet is blocked by the star. This effect, predicted to lie at a level near 10^{-4} , has been very difficult to separate out from various instrumental variations associated with thermal changes in the STIS instrument during its orbit. A paper describing the analysis is in preparation (Charbonneau, D., Brown, T., Noyes, R. and Gilliland, R. "New STIS Observations of the Transiting-planet System HD209458", XIXth IAP Colloquium, Paris, France, June 2003).

We also have been granted HST time for a forthcoming observation (not yet scheduled) using STIS to obtain additional data on HD 209458 during the planet transit; these data will span a wider wavelength band and allow us to search for additional atmospheric absorbers or scatterers such as Rayleigh scattering, water bands, and/or strong alkali metal bands. These observations should allow us to distinguish between models with a high cloud deck and those with no clouds but reduced chemical abundances.

Finally, we have investigated the idea of using the NICMOS instrument on HST to search for the presence of water in the atmosphere of HD 209458 b via the very strong water band at 1.4 microns. Our investigation indicated that this should be possible, and therefore we have proposed to STScI for HST time to carry out this important observation.

4. The HAT Project

We have begun a project to develop a network of very small telescopes, known as HATs, which have the capability of detecting transits of extra-solar giant planets in orbit around nearby relatively bright (8 to 13 magnitude) stars. Recent scientific results, both on HD 209458 (see above) and on OGLE-TR56b (a transiting planet discovered by co-Investigator Sasselov and collaborators), have shown the huge amount of information that transiting giant planets can bring about the formation and evolution of planetary systems, and we can expect this field to increase in importance as the scientific community prepares for the Kepler mission to detect transiting terrestrial planets.

The HAT telescopes are similar to the STARE telescope that made the first detection of the transits of HD 209458b. Through the generous long-term loan by the ROTSE-I project of five high-quality 10 cm aperture lenses, plus 6 Apogee Ap10 2k \times 2k CCD detectors, we have been able to construct 5 HAT telescope units. (The telescope mounts and enclosures were purchased through internal SAO funds.) The first of the HAT telescopes (known as HAT-5) has now been installed on SAO's Fred L. Whipple Observatory on Mt. Hopkins, Arizona and is presently undergoing shakedown tests.

Plans for Third Year

During year 3 of this grant, we intend to exploit the MMT Hectochelle to seek detections of extrasolar giant planets in fields containing a number of candidates, thereby obtaining significant efficiency gains over instruments that survey one star at a time. An important stellar field for investigation is the Kepler field, because of the very exciting possibility of followup precise photometry of stars with close-in giant planets, in order to detect the reflected light from the planets via its phase changes during the orbits. We also will continue observations with the upgraded AFOE spectrometer on precise radial velocity observations of bright stars, plus follow-up on some of the sources detected by the Hectochelle, as opportunities permit.

During year 3 we plan to install the four additional HAT telescopes (beyond HAT-5) at mountaintop observatories. Two of them will go to the FLWO Observatory in Arizona, alongside HAT-5. The other two will be installed at SAO's Submillimeter Array site on Mauna Kea (MK), Hawaii. This superb site, lying three hours west of FLWO, will enable initial network operations that effectively lengthen the observing day by 50%. (Photometry at the sub-1% precision required for transit detection requires that the star zenith angle be less than about 50°, which for an object on the equator limits observing time to about 6 hours; the combined FLWO/MK network will lengthen this to about 9 hours.) This should lead to very significant gains in the probability of covering complete transits, and of detecting successive transits; in turn this will significantly improve the overall detection rate of transiting giant planets over comparable observing time spent at a single site. Because all HAT telescopes are essentially identical, it should be readily possible to combine the coordinated images of the same star field for two sites into a set of single light curves.

Also during year 3 we will begin site selection for moving one of the three FLWO HATs to Tenerife, in preparatory to initiating (in the following year) operation as a 3-station network. This network will span 140° in longitude, or a total time lapse of 9.4 hours, thereby extending the useful time for continuous observations to some 15.4 hours. At this point, the HAT network will be a truly forefront tool for detecting transiting planets.

References published during 2nd year

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